Performance Evaluation of Network Centric Warfare Oriented Intelligent Systems

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Abstract

The concepts of Network Centric Warfare [Alberts et. al 1999] and its sibling Knowledge[1] Centric Warfare are critical elements in achieving so-called Information Superiority. Both of these concepts are not limited to military applications only, but are also suitable in the areas of business or daily life. For the latter however, we should remove the term "warfare" to suggest more appealing applications. The Knowledge Centric aspect is critical in achieving effective Information Superiority *"To transfer knowledge, the receiver's context and experience must be taken into account. The intended result is information is transferred in context instead of with no context.*[Harris, D.B. 1996]

The main question remains not only what Network Centric (NC) and Knowledge Centric (KC) are but also how these concepts can effectively be used to pragmatically achieve Information Superiority. The purpose of this paper is to discuss the NC and KC aspects including network configuration, functions of different nodes of the network, the intelligence required to facilitate KC by providing contextual information dissemination. The discussion of the key infrastructure elements will provide the foundation for exploring the performance evaluation of NCW oriented intelligent systems.

The warfighter desires the 'right' information at the 'right' time. Such information can be defined as contextual. The solution for contextual information dissemination requires intelligent information processing within the nodes of the communication network. The architecture required to support such intelligent nodes is described in this paper.

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[1] Knowledge 1 obsolete: COGNIZANCE 2 a (1) : the fact or condition of knowing something with familiarity gained through experience or association (2) : acquaintance with or understanding of a science, art, or technique b (1) : the fact or condition of being aware of something (2) : the range of one's information or understanding <answered to the best of my knowledge> c : the circumstance or condition of apprehending truth or fact through reasoning : COGNITION d : the fact or condition of having information or of being learned <a man of unusual knowledge>. From Merriam Webster's Dictionary on line http://www.webster.com/cgi-bin/dictionary

I. Introduction

The definition of the problem space must be declared before evolving a solution to a particular problem within the scope of Knowledge Centric Warfare. For the purpose of this discussion the problem space can be decomposed into four main components:

1. **The battlespace** – the topology of the physical space where the action is taking place, the physical laws, the involved equipment and the entities' physical attributes
2. **The doctrine**, rules of engagement, and policies,
3. **The communication networks** – where information to support coordination of effort and execution of moves is transported,
4. And finally, **contextual information packaging and dissemination.**

A. The World, Battlespace, and Battlespace Decomposition

The battlespace is a model consisting of the geography of the region, the position and capability of friendly, neutral and opposing units or entities. The entities are expressed as sets of physical and cognizant properties including models of maneuver, tactics, and combat capability. Based on physical and cognizant properties and commander's goals, these entities may assume either combat or combat support postures. These entities are the players within the battlespace. The battlespace problem is a collection of issues, which the players must overcome to achieve mission successes or to win a war.

The battlespace is partitioned into domains. The domains are decomposed to reflect functional responsibility of a particular entity. The entities responsible for these domains are dispersed throughout the battlespace and have a need to communicate and collaborate. The battlefield problem space is complex and subject to constant change due to various factors such as weather, new threats, new tasks, and unavailability of planned resources. These entities need an information environment, which facilitates a capability for dynamic configuration/reconfiguration in order to meet their need to rapidly form different mission–specific teams, to be aware of their changing environment, and to have contextually pertinent information temporally reflecting the fluidity of the battlespace.

B. Network Centric and Knowledge Centric

Metcalfe's Law[2] suggests the power of information dissemination contained within a fully connected network, however it says nothing about the quality and contextual relevance of the information such network can provide. This power manifests itself in the large amount of potentially available information accessible at the nodes of a network. The question we must ask ourselves is what is more desirable, a large volume of information, what ever it might be, or a short but contextually relevant extraction from that large volume.

Large volumes of redundant or irrelevant information will overburden the communication channel rendering the NC aspect less effective or useless. Prioritizing and disseminating information based on the need to know and as recipient's task critical requirement can further save the communication bandwidth. Determining information pertinence and packaging the information within a specific level of granularity, required by the recipients, becomes therefore paramount in implementing the paradigm.

To analyze the NCW and KCW approaches we have to consider current and evolving topological architectures of tactical networks. However, the topology of the network is a "parcel delivery infrastructure" and while it erroneously seems to have no bearing on the actual context it is important for multilevel modeling. The success of KCW specifically depends on the contextual information dissemination. To achieve contextual information dissemination requires intelligent information processing at every node of the network, except routers or similar functioning devices, where information is received and sent.

C. Communication Network of the Battlespace

Shown below in Figure 1 are representations of possible network configurations. Fig.(b) is best suited to depict a typical military network, which represents for example, communication between ground force companies, battalions, or navy ships at sea. The hubs of the network, shaded gray in Figure 1 b, may also represent unit clusters consisting purely of sensors, robots, and people or a heterogeneous composition. For example, an M1A1 tank can be viewed as a hybrid of sensors, weapons, and people and can also represent one node in an armor company network.

[2] Metcalfe's Law, which states that the usefulness, or utility, of a network equals the square of the number of users. Named after Robert Metcalfe, the founder of 3Com Corporation and designer the Ethernet protocol.

The NC paradigm suggests the topology of Figure 1 (c), however such topology is very difficult to achieve for several reasons;

- Unavailability of required electromagnetic bandwidth,
- Line of sight limitations
- Doctrinal, echelon dependent communication requirements.

The topology of a network for brigade and below is shown in Figure 2. Additional battalions were omitted for simplicity.

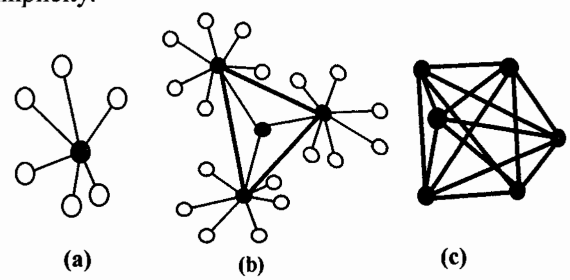

Figure 1. Network configurations
(a) Simple star, (b) Cluster of stars,
(c) Fully connected

The topology of Figure 2 lacks connectivity between battalions and companies of adjacent brigades. The elements of battalions are highly mobile and frequently come within weapons range of each other and must be aware of each other presence to avoid fratricide. The problem is further exacerbated when these elements also belong to different brigades. The situation awareness information, of units belonging to this brigade, must travel up to the level of the first brigade, must later be transmitted to the second brigade, and finally must be disseminated to the lower echelons. Whether the network topology remains the same or changes, **the need for intelligent processing at the nodes is critical to contextually evaluate the information about who done what and who needs to know about that first.**

D. Knowledge Centric Network

Understanding the information requirements for individual recipients is essential to achieve effective contextual information dissemination within the KC network. It is outside the scope of this paper to explore all the requirements for all potential individual recipients on the battlefield, however a general architecture must be defined. In order to be effective, the architecture must answer the following questions:

1. **What is the echelon of the recipient**
2. **What duties does the recipient have at a specific instance of time**
3. **What is the state of battlefield variables**
4. **What information must be sent first**

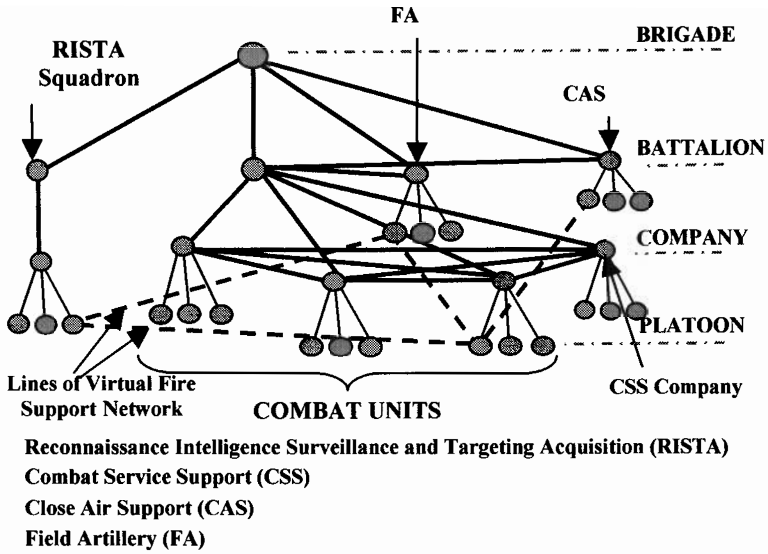

Figure 2. Communications network for brigade and below

5. **What is the level of granularity of the information required**
6. **When must the information be sent**
7. **What does the recipient already knows**

The major elements of the KC architecture are based on knowledge about the area of responsibility or the duties and tasks assigned and the echelon level of the individual. Such profiling is doctrinally driven and available in field manuals. The content of the information set is modeled on those attributes. The required information profile is not a template, or a table to be filled out to meet the information requirements, but is a mapping function, which transforms raw information and data into the information requirements for individual recipients (Figure 3).

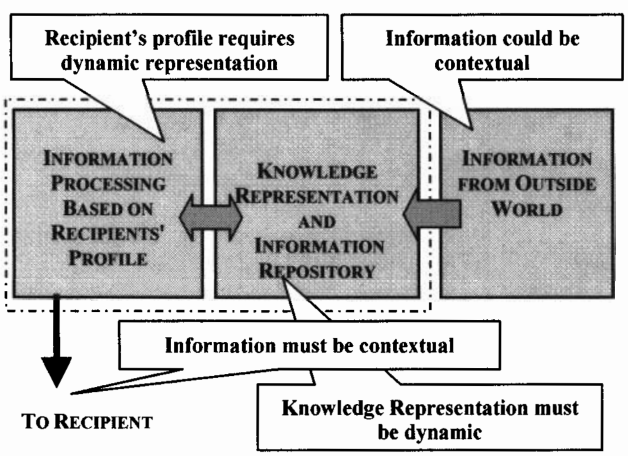

Figure 3. Simple Information Processing based on Knowledge Representation

The information profile contains attributes to answer questions such as **what echelon is the recipient**, **what duties does the recipient have at that instance in time, where is the recipient, what information must be sent**, and **what is the level of granularity**. To answer the question **what is the state of battlefield variables** requires an updated world model, a multilevel knowledge representation of the environment. The multilevel knowledge representation of the environment will provide the required inference to answer the question of **when to send the information**. The question **what does the recipient already know** can be answered by maintaining a repository of previous transactions local to the information source.

II. Intelligent Node Architecture

Intelligent agent architecture, defined in earlier work [Dawidowicz E, 1999], is also applicable to the intelligent node architecture, but requires modification and improvement to qualify as an intelligent node described here. The improvement is required specifically in the area of adaptation of the intelligent node to the changing battlespace environment. A likely candidate for such improvement is the application of an intelligent controller as described in semiotic modeling [Meystel A, 1995]. This model is applicable to both individual intelligent nodes As well as to a cluster or clusters of collaborating intelligent nodes. The analogy to intelligent automatic control is evident and emphasized.

The think-before-act or the actuation simulation loop is the foundation of the proposed architecture and is shown in Figure 4. The Elementary Loop of Functioning is a goal driven process. Before selecting a possible response for a specific goal it generates, using the World Model, several potential actions (this is not a complete sentence). The best- actions are selected and used to stimulate the simulated world (or environment). The simulated sensory response is collected, processed and fed back into the world model. This constitutes the contemplation of think-before-leap process and is analogous to imagination.

A. Knowledge Representation Repository

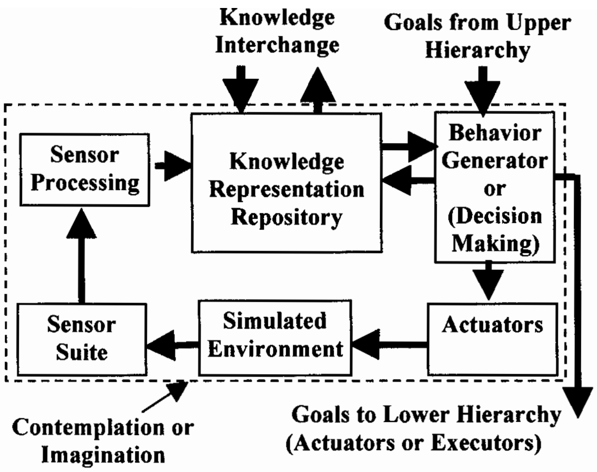

Figure 4. The Elementary Loop of Functioning (ELF)

The Knowledge Representation Repository (KRR) in general, is a description of the world. The KRR contains the model of the anticipated and learned environment or the battlespace. Specifically KRR[3] is a set consisting of, but not limited to models of:

a) Representations of terrain, in the sphere of interest, with elevation data and features,
b) Physical geographical data of the terrain such as soil properties, water levels, variations due to tide or precipitation,
c) Physical objects that are known to appear in that environment,
d) Object properties,
e) Objects which were detected in the environment,
f) Geo-spatial location of the physical objects,
g) Associative relationships between objects,
h) Rules and procedures associated with certain conditions of relevant battlespace,
i) Specific activities the objects which are in the modeled environment,
j) Meteorological data,
k) Profiles and information requirements of the users,
l) Ontology for textual discourse

The KRR is both, a process and a repository of information subject to a phenomenon called reflection [Meystel A. 1995, p68]. The KRR will contain knowledge extracted from doctrine, pollicies, operational requirements, mission plans, maps, map features, equipment capability, and situational awareness.

The KRR is updated by exchange of information between KRRs on the network. The rules of information exchange depend on the geographic proximity between the nodes and their functional interdependence. The rules within the KRR are also updated using the Elementary Loop of Functioning process discussed later and in [Meystel A. 1995, p67].

To be valuable within the KCW paradigm the KRR must contain the representations of the information interchange on at least three different levels; on its own level, on an equivalent level of functionally equal or functionally different, and on one level above and one level below. These levels are synonymous with echelons, while the functionality is derived from the service these echelons are expected to perform and are critical in heterogeneous KCW. For example this diversity in functional representation will be instrumental in determining the context of the message interchange, in close air support mission, between the Army and Marine warfighters on the ground and the Navy and Air Force pilots who provide the air support to them.

B. Decision Making

The Decision-making process (DM) is initiated by a goal, either given by a decision-maker from a level above or in response to critical changes detected within the KRR. The detected changes within the KR become critical when the DM can detect or anticipate possible deviations from the plan. The goal of the DM is to provide tasking to the external actuators to correct the deviation from the plan under execution.

The DM within the intelligent node compares a current situational picture to the picture anticipated based on a plan in execution. The DM also prioritizes, required to be performed tasks, based on a particular situation, or a particular set of states. The rules of KRR are used to determine the priority of a particular task. The prioritization can be illustrated in a scenario when a particular intelligent node is involved in a CAS mission and the planes are a few minutes from delivering their munitions on the enemy positions. The first priority of that particular node is to prevent a potential fratricide situation, by providing the pilots with the latest positions of the friendly forces in the proximity of the anticipated kill zone. The second priority is to notify the pilots of where the enemy is. However, when an enemy antiaircraft threat is detected, an intelligent node must make the threat notification to the pilots first and then provide CAS critical information.

C. Elementary Loop of Functioning

The DM is more complex than a typical follow-the-rules process. It can 'reason' by invoking the Elementary Loop of Functioning (ELF) [Messina E, Meystel A. 2000] Figure 5[4]. By using the information in KRR it forms a hypothesis as to what needs to be done. To test the hypothesis a

[3] The modeling properties reflect a specific KRR level of representation and hence employ a particular resolution or granularity appropriate to such level.

[4] Please note that Figure 5 is significantly different from Figure4. The significant different is in another ELF which runs from DM and another ELF within KRR. This architecture allows the intelligent nodes to "correct" its models on different levels of resolution based on knowledge representation shared and received.

command or a set of commands is sent to the Actuator block. The Actuator block is a set of simulated actuators or a set of processes expected to simulate task actuation.

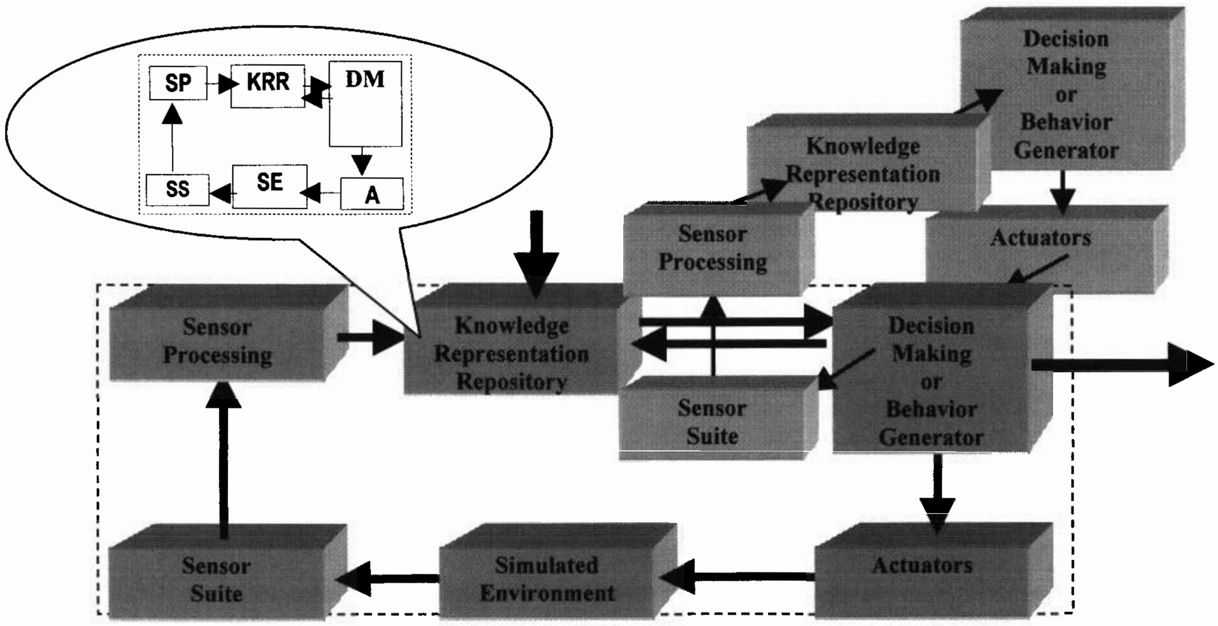

Figure 5. Elementary Loop of Functioning with multi-resolution ELFs

D. Simulated Environment

The simulated environment (SE) is a subset of KRR. Only the elements of KRR, pertinent to the immediate domain within which the simulation is to occur, are incorporated in the simulated environment. The simulated actuators are activated within the SE. The Sensors Suite (SS) detects the resulting changes, from actuation, within the environment caused by the simulators.

E. Sensory Processing

Sensory Processing (SP) processes the changes in the SE, detected by the SS. The SP block fuses and correlates information as it would to in the real environment. The processed sensory information is sent to the KRR.

F. Completing Contemplation Loop

The results of the simulation are compared to expected values. When the simulated results are acceptable the DM will perform a required action by sending an appropriate message to the outside world, or to another node on the network. Please note that during all processes within the large ELF, smaller ELF process run within the larger loop elements. The number of nested loops depends on the required level of granularity or resolution for a particular contemplation cycle. Usually one level above and one level below are sufficient, but rarely may require several levels down. The execution of different levels of ELFs, within each individual block, is dictated by a requirement for higher or lower granularity models. The DM, KRR, and SE blocks specifically require ***multi-resolution*** modeling.

III. INTELLIGENT NODE AS AN INTELLIGENT CONTROLLER

The intelligent node is an intelligent controller, which continually adapts itself to the environment. If allowed, it initiates situational awareness information exchange between other intelligent nodes based on established relations. The relations are determined by homogeneous or heterogeneous combat cells, which are formed into task/mission teams. Such teams can also be called habitats. The habitats are not bound to a single geography, they may be globally distributed, and can consisting of humans, intelligent agents and robots.

The purpose of the intelligent node, in the KCW intent, is to contextually process and disseminate information. To achieve the KC aspect, the intelligent node should have the knowledge representation of the receiving node. This does not mean that that it must contain all of the KRR of the receiving node, but the knowledge representation must be sufficient to formulate a contextual message. The contextual message must be formulated, prioritized and timely sent to the receiver containing only the information required.

The formulation of messages and informational content is based on the need to know and the security level of the receiver. Both the need to know and the security levels are based on doctrine, policies and plans.

The ELF modeling of the intelligent node is not limited to KC information exchange. Such modeling is an invaluable tool for mission planning, mission execution, and replanning. The intelligent nodes also serve as a useful asset in filling the Critical Commander's Information Requirements (CCIR) and Priority Intelligence Requirements (PIR).

A. Intelligent Node in Two Echelons

The ELF model supports the information flow pattern of a military organization. Figure 6 represents instances of a battalion and three subordinate companies or brigade and three subordinate battalions and depicts the purpose of the individual components.

IV. Performance Evaluation

Before discussing performance evaluation, Measures of Effectiveness (MOE) and Measures of Performance (MOP) must be point out. The MOE and MOP are important abstractions used for system evaluation [Noel Sproles, 2001]. The MOE provides the formulation of purpose or need, while the MOP refers to the performance of a particular entity developed to fill that need. The system of Intelligent Nodes responds to the MOE: 'Ability to provide task pertinent and concise information to the user'. The definition of MOP is more complex and requires consideration of both individual components and a system of such components.

The performance evaluation of individual intelligent nodes must reflect the echelon levels they are modeled to represent. Since events evolve faster at the lower echelons, the intelligent nodes must evaluate information proportionately faster. This is reasonable since lower echelons are near term planners and are concerned with the more immediate future. In general, the granularity of information is finer at the lower levels, but requires shorter term planning. The criteria for performance evaluation therefore cannot be applied equally to a node, but must reflect the echelon and functional purpose such an intelligent node serves in the KC network.

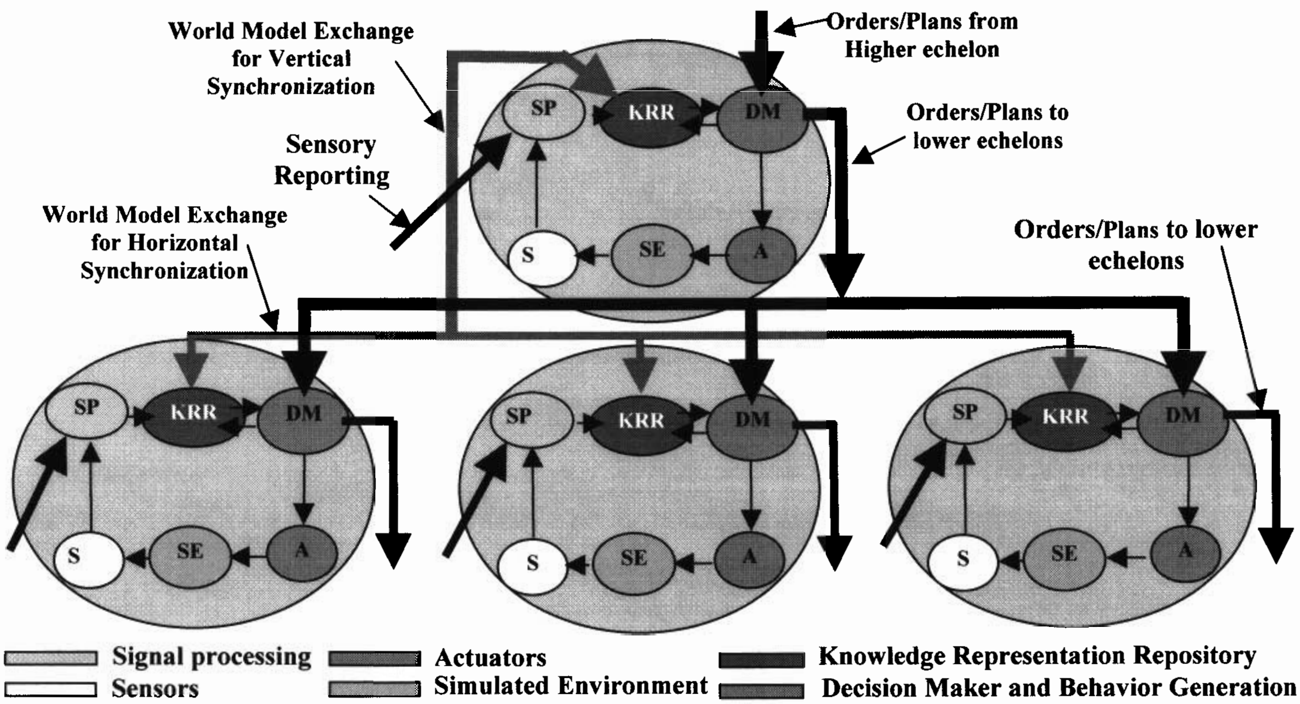

Figure 6. Information exchange between command and three subordinate units

The Intelligent Nodes are but elements in a system where the value of the system is greater then the sum of its parts. The evaluation criteria are therefore not scalable from individual components to the system. The architectural framework together with the performance requirements provides the basis for evaluation. Below are listed some architectural and performance requirements.

A. Architectural Requirements of Intelligent Nodes

1) Completeness of the Knowledge Representation of the battlespace reflecting a specific level of granularity. The Knowledge Representation model must reflect specific echelon and functional levels
2) Ability to adapt the Knowledge Representation model to changing and evolving battlespace

3) Develop Decision Generator/Behavior Generator capable
   a) of dealing with incomplete and uncertain world representation models,
   b) developing hypothesis or a set of assumptions to resolve uncertainty,
   c) to simulate the hypothesis/action,
   d) to evaluate the results of simulation,
   e) and finally to select the "best" result as a decision/action.
   f) to enrich the Knowledge Representation Repository with a new "rule" if a particular hypothesis yields a better solution.
4) Develop a process, identifying the important elements to process
5) Ability to dynamically prioritize tasks to reflect the current situation
6) Natural language or controlled natural language understanding.
7) Ability to express reasoning using natural language
8) Ability to share knowledge representation among other Intelligent Nodes

B. Performance requirements

1. The Intelligent Nodes must be evaluated based on their specific echelon and functional levels.
2. The lower the echelon, the greater the requirement for faster processing.
3. The speed of processing must be examined against the methodology used in information processing.
   a. Number of possible permutations / hypothesis resulting from evaluating the environment and the actions/goals of the entities involved.
   b. Optimal selection of the best permutations
   c. Formulation of hypothesis and ability to evaluate them for optimum results.
4. Number of granularity levels of Knowledge Representation used in the hypothesis evaluation process

Discussion and Conclusion

The performance evaluation of Intelligent System is a difficult process. It is especially difficult since the definition of intelligence remains largely elusive. Perhaps the issue is not what intelligence is, but rather how it must assist in resolving an unspecified problem. Digital computers have their limitation " Might it be that the symbol grounding problem is created by the digital computer rather than solved by it? Perhaps the idea of abstract information or symbols is a computer-based fiction?" [Hoffmeyer J, 1997]. The purpose of an Intelligent Node based system is not to model intelligence in its pure sense, but to produce a pragmatic tool to assist in dealing with the information explosion.

The tale of a few blind men and their encounter with an elephant comes to mind. They were allowed to touch the animal to learn what it was. After examination they shared their findings and learned that the animal is a huge barrel standing on four pillars with a large hose in the front and a dust sweeper or fly swatter in the rear.

A system with a single layer of resolution may just produce the same view of the world as that of the elephant perceived by the proverbial blind men. If the blind men could go beyond the single resolution in their verbal description and were able to share among themselves their tactile findings in several levels of resolution, then their perception of the animal would appear closer to the truth.

The Intelligent Nodes described here are analogous to our proverbial blind men, but only in the ability to share information that they sense. When modeling described here is implemented, the discourse among the Intelligent Nodes will be much richer, for they will be able to share information with a sufficient complexity, however not in bulk, but in context. By sharing contextual information they as a system will arrive at a better understanding of their world.

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